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Cross-Layer Optimization and Adaptation in Wireless Mobile Ad Hoc Networks

Prepared For:
"Workshop on Cross-Layer Issues in the Design of Mobile Wireless Tactical Networks"

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Overview

- Objective
- Wireless Ad Hoc Networks Characteristics
- Cross-Layer Design Factors and Feedback Stack
- Cross-layer optimization and adaptation improves performance in the user plane
  - Fast-handoff for mobile using triggers (**MOSAIC/CERDEC, LTS, AJCN/DARPA/CERDEC**)
  - Adaptive application based on signaling (**AJCN/DARPA/CERDEC**)
- Cross-layer optimization improves performance in the network management plane
  - Cross layer Issues in domain auto-configuration (**ARL CTA C&N**)
- Conclusions

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Objective

"Obtain performance improvement of the end-user, application and overall system using cross-layer feedback and optimization"

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Issues in Wireless Ad hoc Networks

- Mobile Wireless Tactical Ad hoc Networks Characteristics
  - Resource limited (b/w, power)
  - Changing topology (node mobility, networks splitting/merging)
  - Intermittent connectivity
  - Heterogeneous
  - Varying user needs (changing mission needs)
- Mobile Wireless Tactical Ad Hoc Networks Requirements
  - Rapid handoff
  - Rapid autoconfiguration and reconfiguration (minimize network disconnect time)
  - Efficient use of limited resources (low overhead, energy aware)
  - Traffic differentiation and QoS support (e.g priority-based traffic)

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Cross Layer Design

- Goals in cross-layer adaptation and optimization
  - Increase network throughput (i.e. reduce overhead)
  - Reduce latency, delay in a mobile environment
  - Reduce network disconnect time
  - Adapt protocols across layers and collaborate for reduced power consumption
  - Improve application performance
  - Increase user satisfaction
  - Better utilization of available resources

- Cross-layer design and optimization approaches
  - Exchange cross-layer information (e.g. end-user feedback provides better control)
  - Cross layer feedback can be useful both ways
    - lower-to-upper
      - Application adapting a rate according to TCP/RTCP feedback
    - upper-to-lower
      - Application requirement enables link layer/routing to adapt its error correction
  - Consider physical layer, network, transport and application characteristics and constrains in optimization mechanisms

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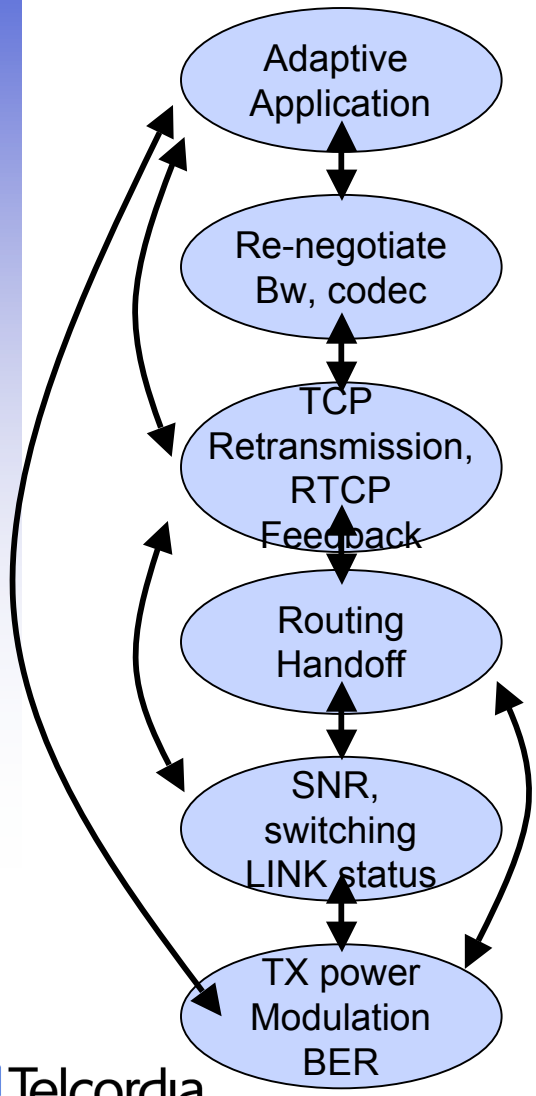
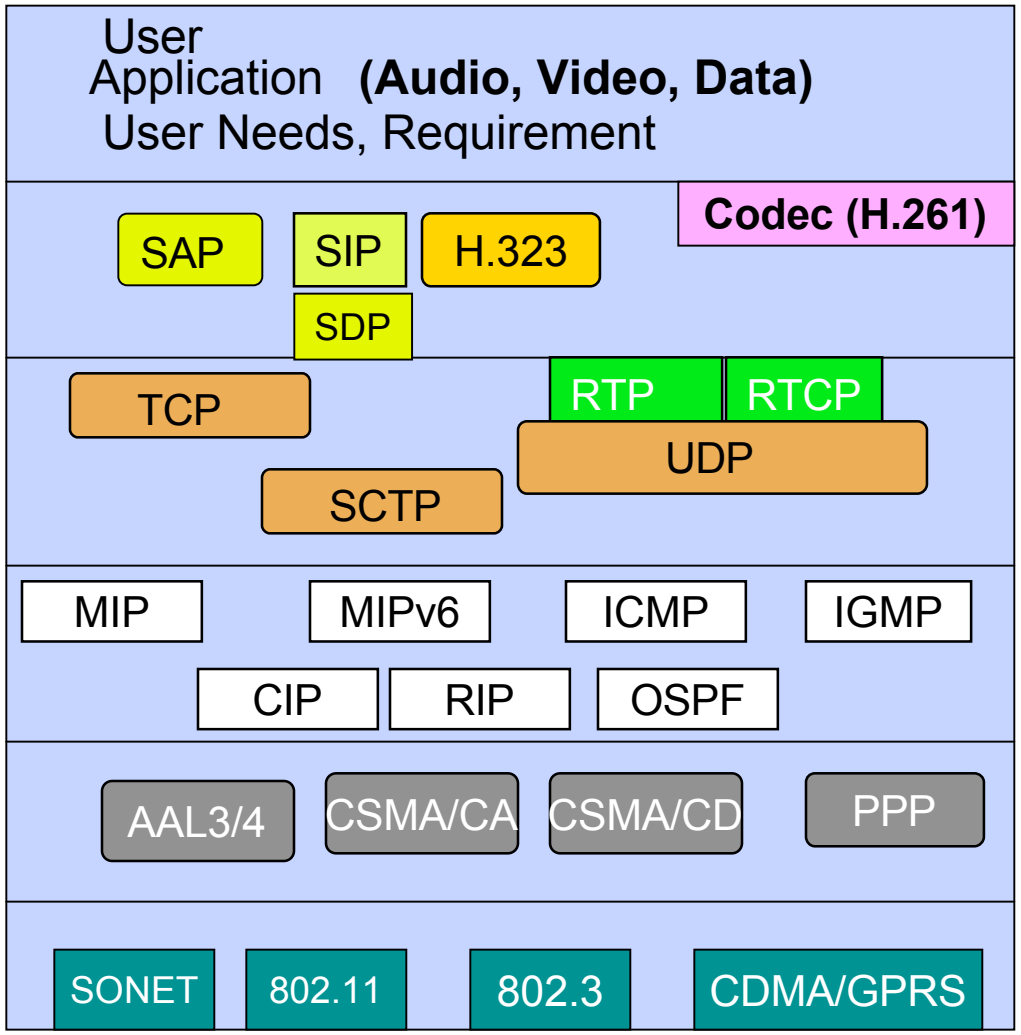
Cross-layer Feedback in IETF Multimedia Protocol Stack





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L1, L2, L3 and app Triggers for Fast-Handoff

- **Objective :** In order to maintain L3 sessions during handoff, L2 and other triggers are required
  - Triggers are the underlying mechanism for enabling seamless handoffs where possible
  - Triggers can be generic (link_up, link_down, etc)
    - It is a policy decision to determine why and when it would fire a trigger.
    - Enables proprietary differentiation in lower layer mechanisms while maintaining a standard interface
    - Firm boundaries between MAC layer and Physical layer may not be needed
  - L3 Trigger
    - ICMP Router Advertisement
    - Server Advertisement (e.g., DRCP)
  - Application Layer Trigger
    - GPS coordinate-based trigger
  - Triggers could be extensible. Vendor proprietary triggers?

Standardization Efforts:

- TRIGTRAN (Trigger for Transport), SEAMOBY (IETF), MOBOPTS (IRTF)
- IEEE 802.21
- CDMA 2000
- Broadband Radio Access Network (BRAN)
- Mobile Broadband Wireless Access (MBWA) Networks

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L2 Triggers for Fast-Handoff

- How can L2 assisted handoff help reduce the transient data loss?
- **WLAN**
  - Events causing the trigger
    - Link_up (which link)
    - Link_Down
    - Link_going_up (which link, when)
    - Link_going Down
    - Domain_crossing
  - Proactive L2 triggering
  - IETF approach
    - Pre-registration
    - Post-registration
  - Combination of 802.11 and MAC bridge
- **GPRS**
  - Attach/Detach, PDP Context Activation/De-activation
- **CDMA 2000**
  - Access Network ID (ANID) change, PPP synchronization

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The Cross-layer Feedback Service Scenario

MAC_SAP Messages Defined within base MAC Spec (802.3/11/16)

+

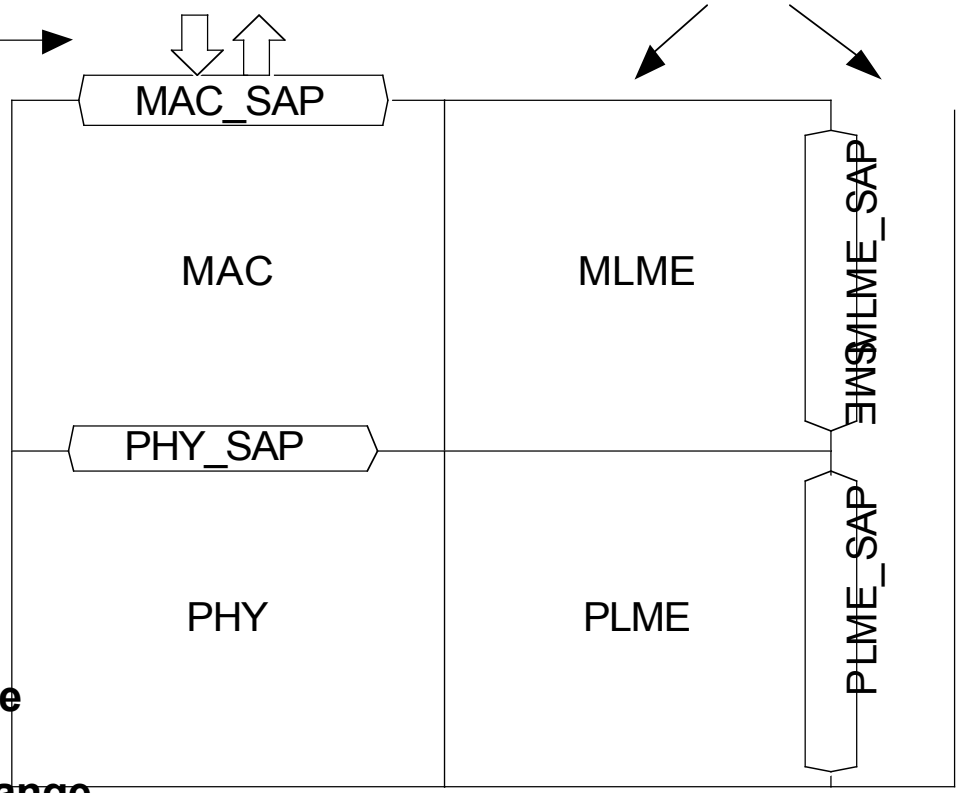
MAC_SAP Messages Defined within HO Spec 802.x[.y]

Messages are generic, E.G.:

- Link_up
- Link_down
- Link_event_pre_indication(what,when)
- Handoff_request(where, why)
- Fetch_base_descriptor(from where)

MAC and PHY implementations determin mapping to these based on their own special cases

Pass triggers and/or roaming decision data through management interface?



MLME – MAC Layer Media Exchange

PLME – Physical Layer Media Exchange

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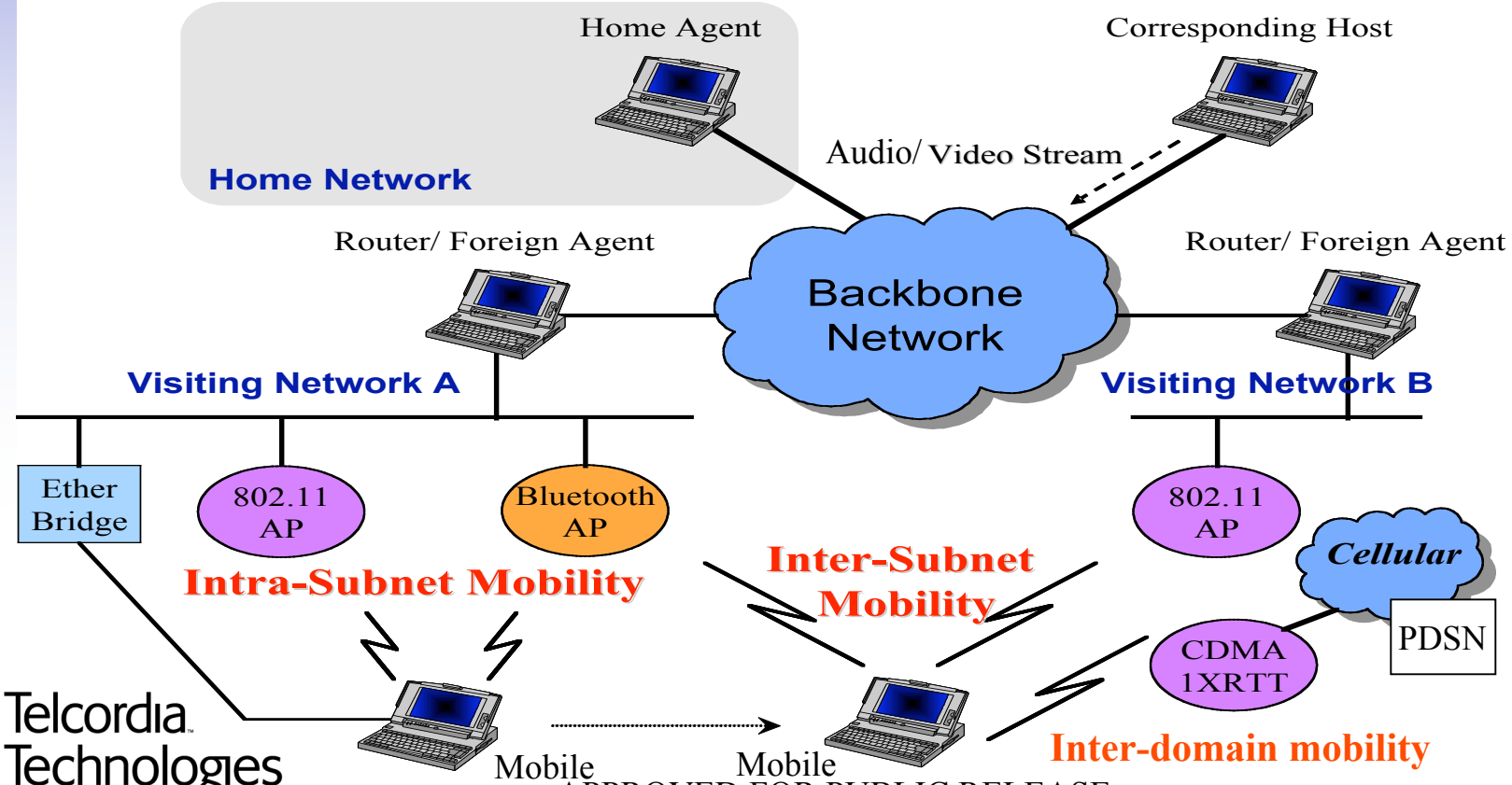
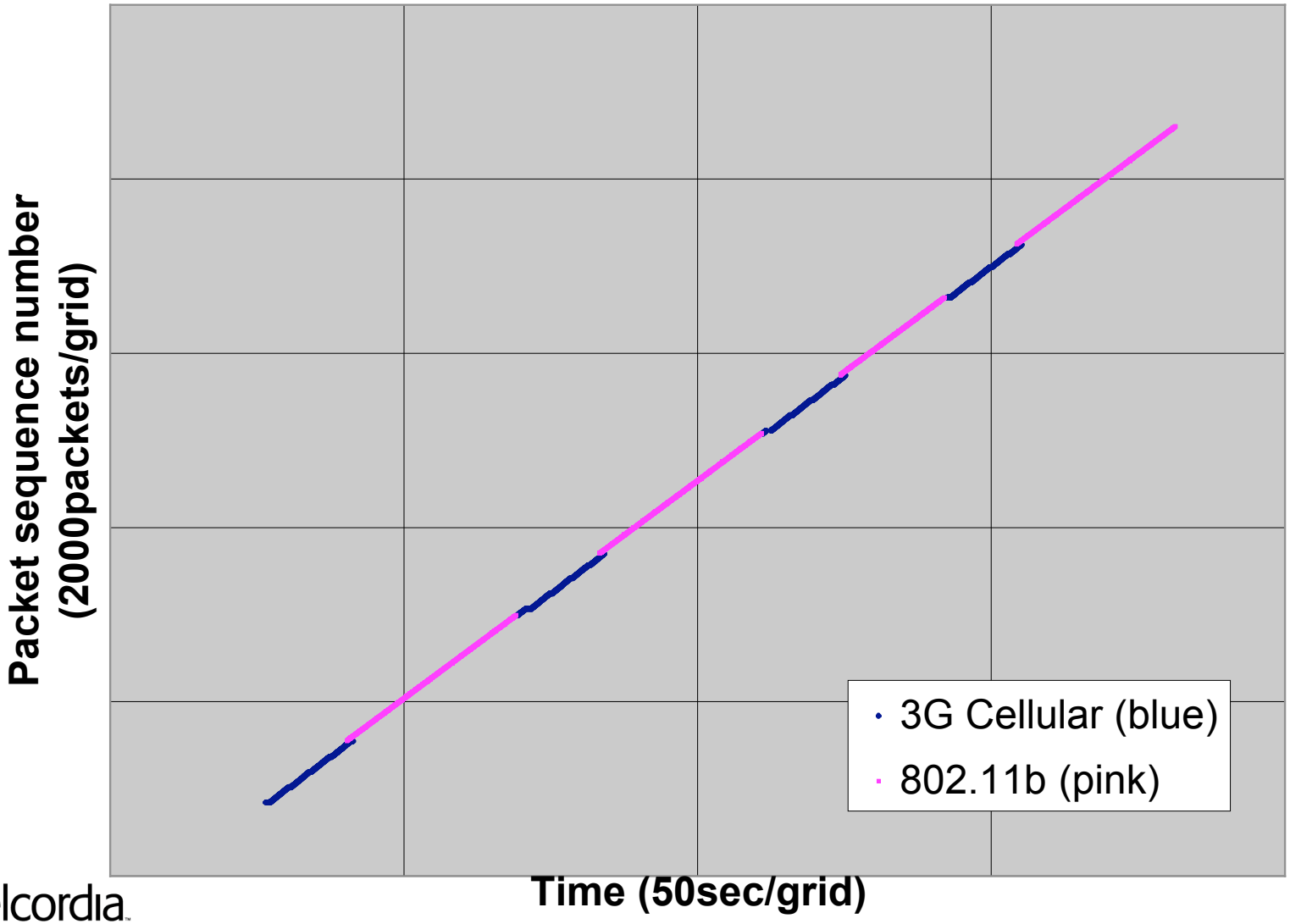
Cross-layer effect on Fast-handoff in Multi-Interface Mobility Management

- L2 assisted Optimized fast-handoff
  - SNR to decide the handoff
  - Use multiple threshold level
  - Choose the right interface to communicate
  - Reduce transient Data loss



SIP-based L2-assisted Inter-domain Handoff (Audio)



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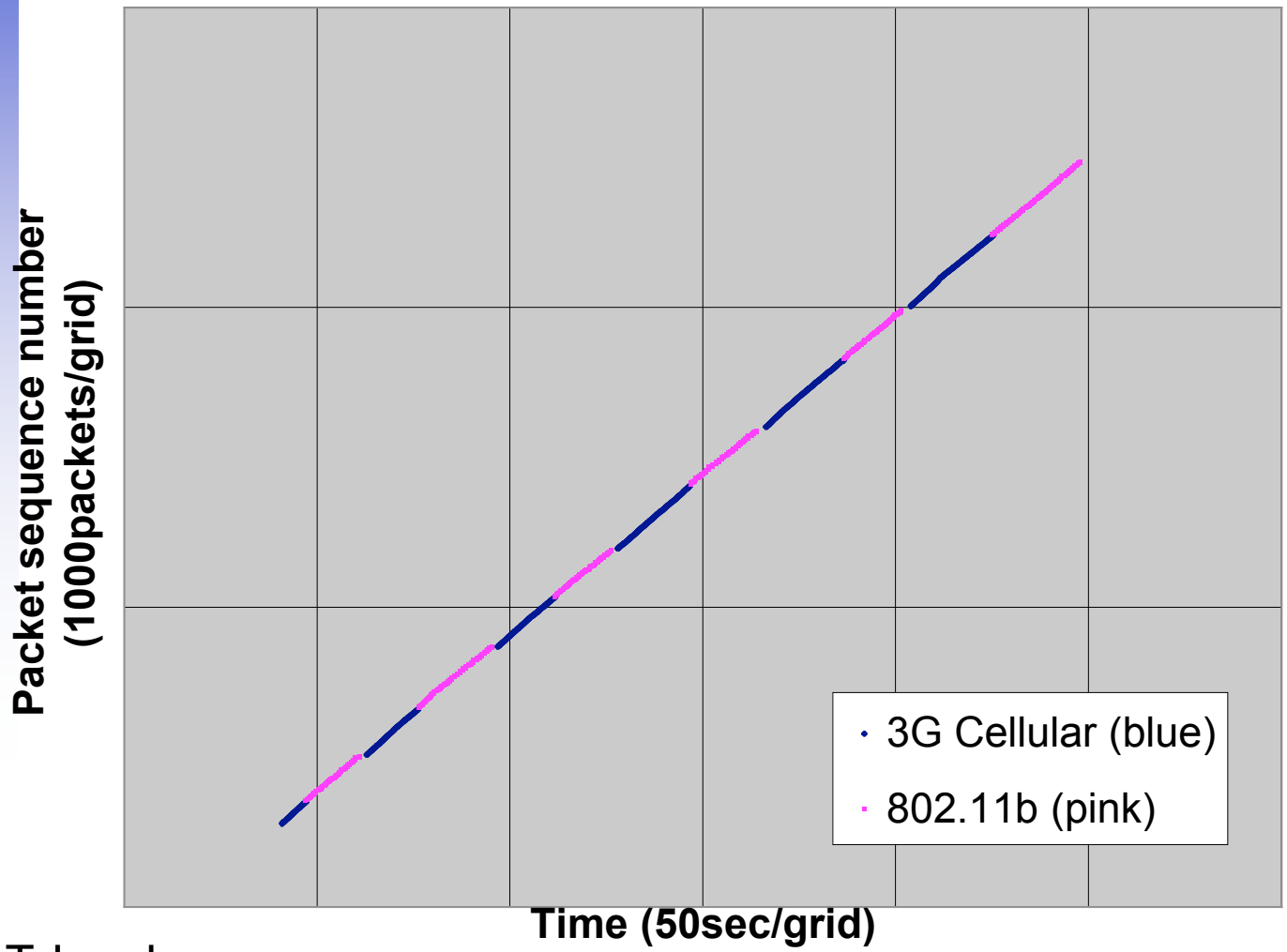
Mobile-IP based L2 assisted inter-domain handoff (Video)



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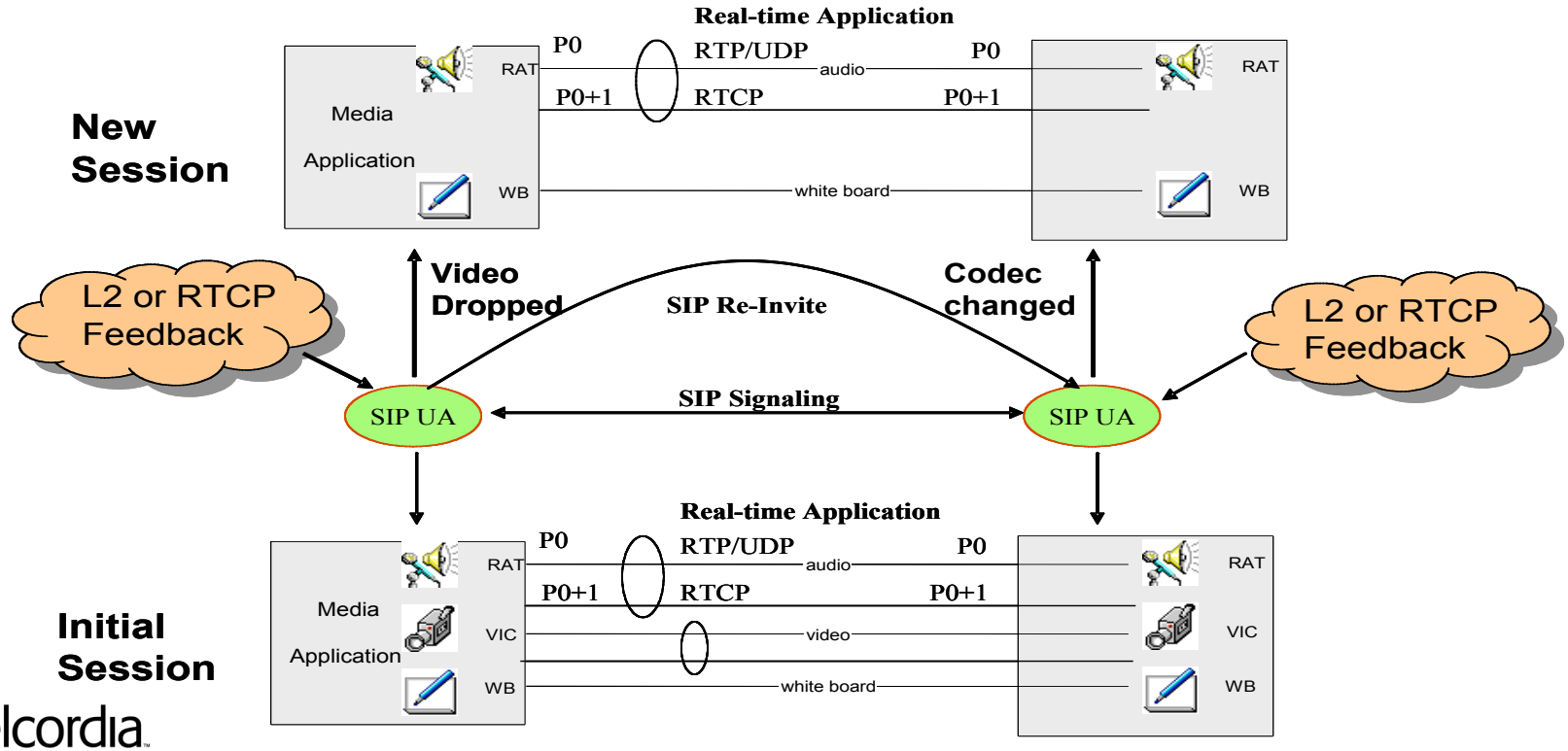
Adaptive Session Management with SIP and RTCP Feedback

- Interaction between SIP (Session Layer) and RTCP (Transport Layer) for adaptive multi-media application
  - Change Codec
  - Change Application
  - Modify required bandwidth



Domains In Mobile Ad Hoc Networks

- Dividing networks into smaller and more homogeneous cells/clusters/domains provides
  - Scalability
  - Manageability
  - Efficiency
- Cells/L2-clusters/L3-domains all represent similar concepts but apply, most times, to different layers in the protocol stack
  - L3 domains = L3 functions and protocols (routing protocol, IP mobility management, location…)
  - Cells or clusters = Lower layer (below IP) functions (MAC, frequency re-use)
  - Higher layer domains = Application and higher layer protocols (security groups, communication groups,…)
- Currently, L3 domains configuration protocols and lower layer clusters/cells are designed independently
  - Independent optimization algorithms
  - Independent protocols (e.g. 802.11 beacon and L3 domain beacon protocol)

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L3-L2 Domain/Cell Autoconfiguration

- Domain Autoconfiguration Protocol Suite performs the following functions (*),
  - Bootstrap and domain configuration maintenance in dynamic networks by means of,
    - Beacon Protocol
    - Algorithms to determine domain merging and splitting domains
  - Create domains that optimize networking protocol performance based on environment characteristics, application and mission requirements by means of,
    - Optimization Techniques for Domain Partitioning
    - Distribution of Configuration Information (e.g. IP autoconfiguration Suite)
- Self-organizing L2 cells or clusters (examples)
  - Dynamic cluster head selection
  - E.g. 802.11 beacon to form L2 cells in both infrastructure and ad hoc mode.

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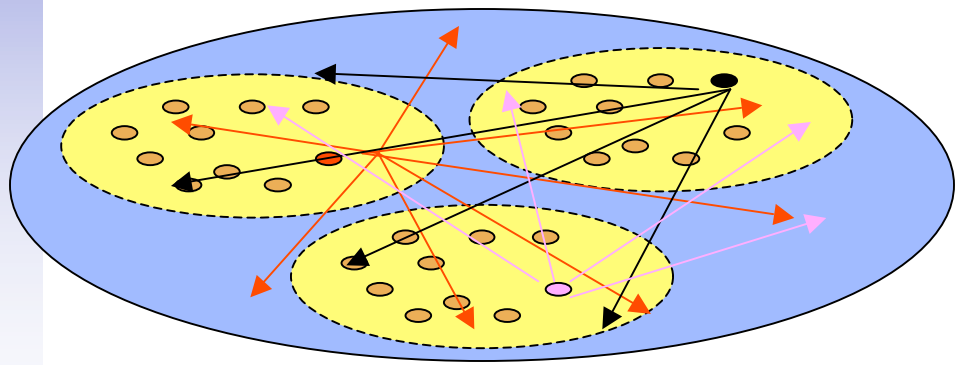
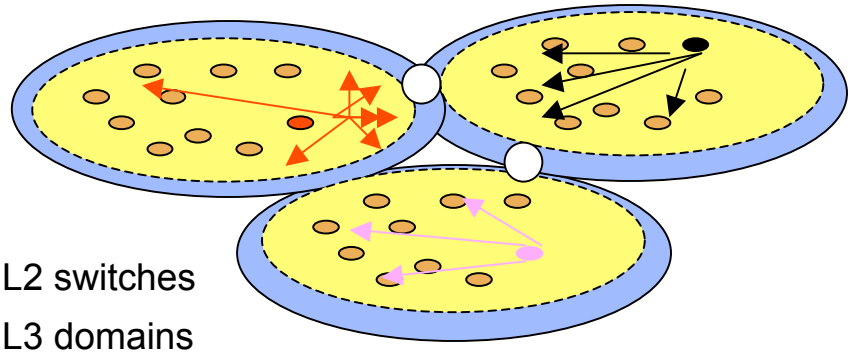
(*Work Carried out as part of ARL CTA Project (C&N))

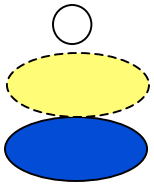
L3 Domains Condition L2 Topology (Reduced Overhead)

- E.g. if performance is not limited by L2 capacity, but by L3 multihop protocol routing, there is a large gain in conditioning L2 topology to L3 domains



Configuration 1: No cross layer feedback
• L3 beacon is a L3 broadcast message
• L3 broadcast is sent also as a L2 broadcast,
• L3 beacon is a large overhead



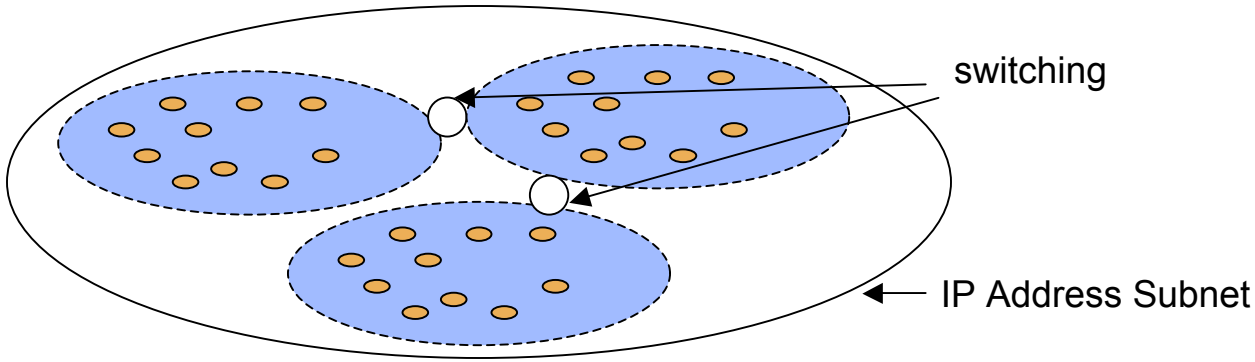


L2 switches
L3 domains
L2 cells/clusters

Configuration 2: L3 configuration conditions L2 topology
• L3 beacon is contained within a cell, thus less overhead
• However, there is an extra cost of enabling L2 switches

Cross-layer Domain Optimization (Efficient Mobility Management)

- Cross-layer domain optimization must consider efficiency tradeoffs between
  - L2 switching and L3 routing
  - L2 mobility management, L3 IP address reconfiguration, L3 mobility management and node location schemes
- Example: L3 IP subnet is composed of several L2 cells where L2 “switches” support inter-cell communication and inter-cell mobility
  - Large L3 IP subnet sizes, ease mobility management functions at the IP layer
    - Large L2 subnets/clusters/cells decrease system capacity (e.g. entails large number of contenders in CSMA schemes or less frequency reuse in FDMA schemes)
    - Small L2 subnets/clusters/cells increase network complexity creating the need of switching entities and possibly need for L2 hierarchy
  - Small L3 IP subnets, i.e. and IP subnet is a L2 cell
    - L2 routing/switching necessary
    - Increased mobility management overhead for L3 (MIP) and higher layer protocols



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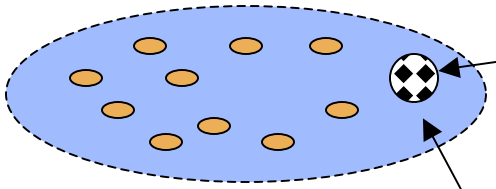
Cross-Layer Protocol Design

- Having two separate protocols at each layer performing similar functions in an uncoordinated manner may lead to
  - Large overhead
  - Example: L2 and L3 beacon



802.11 L2 cell = all nodes transmit at the same frequency and share the channel

Cell Head sends beacon to allow synchronization among the different nodes for MAC layer functions (802.11)

L3 configuration domain = all nodes use the same network prefix, this is a level 1 topological routing domain thus nodes are one IP hop away

Beacon node periodically broadcasts domain maintenance message. Beacon message is relayed by all nodes in the domain

Although L2 beacon and L3 beacon have different goals are maintaining the same topology = Can we optimize cross-layer topology maintenance??

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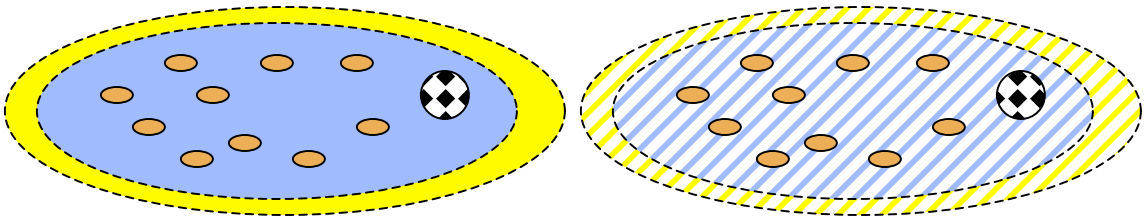
Cross-Layer Issues in Networks Merging

- L2 provides basic connectivity, so L3 domains are conditioned to L2 topology
  - Two networks that were split apart and move so are in range of each other cannot merge as a layer 3 domain unless L2 also supports network merging



Split Networks

- L2 provides triggers to L3 to detect networks split and networks merging thus minimizing network disconnect time, same as with node mobility

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Conclusions

- Cross-layer feedback helps achieve better overall system performance in an ad-hoc wireless network
- Cross-layer feedback can be both ways
- Feedback does not need to be between adjacent layers only
- Although each layer may help other layer to contribute to system's performance, redundancy of cross-layer info may be avoided
- Cross-layer feedback should be considered while designing ad hoc networks
- Fast-handoff due to node mobility, adaptive SIP-based application and domain auto-configuration were cited where cross-layer feedback can be useful

Programs

- AJCN/DARPA/CERDEC. LTS, CERDEC MOSAIC : cross-layer feedback for fast handoffs
- AJCN : SIP-based adaptive application
- ARL CTA C&N : cross-layer design in domain autoconfiguration

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